An Input to NASA's HSF Planning

- The work that we did provides thoughts on two subjects:
  1. A technical mission architecture and,
  2. What it takes to make that architecture executable

- We hope aspects of this work are useful to the HSF planning process

H2M
Minimal Architecture

Why Yet Another Architecture?

NRC Pathway(s)

DRA-5

Mars One

Explore Mars

Inspiration Mars

Modular Mars Architecture

Mars Cycler

Mars Society

Space-X Red Dragon

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Defining a Multi-decade Executable Program

The Science and the Art

An executable program requires balancing several (sometimes competing) constraints:

- Technical Feasibility
- Fiscal Affordability
- Stakeholders' Interest Horizon
- Acceptable Risk
- International/Private Sector Engagement
- Political Realism Across Several Administration

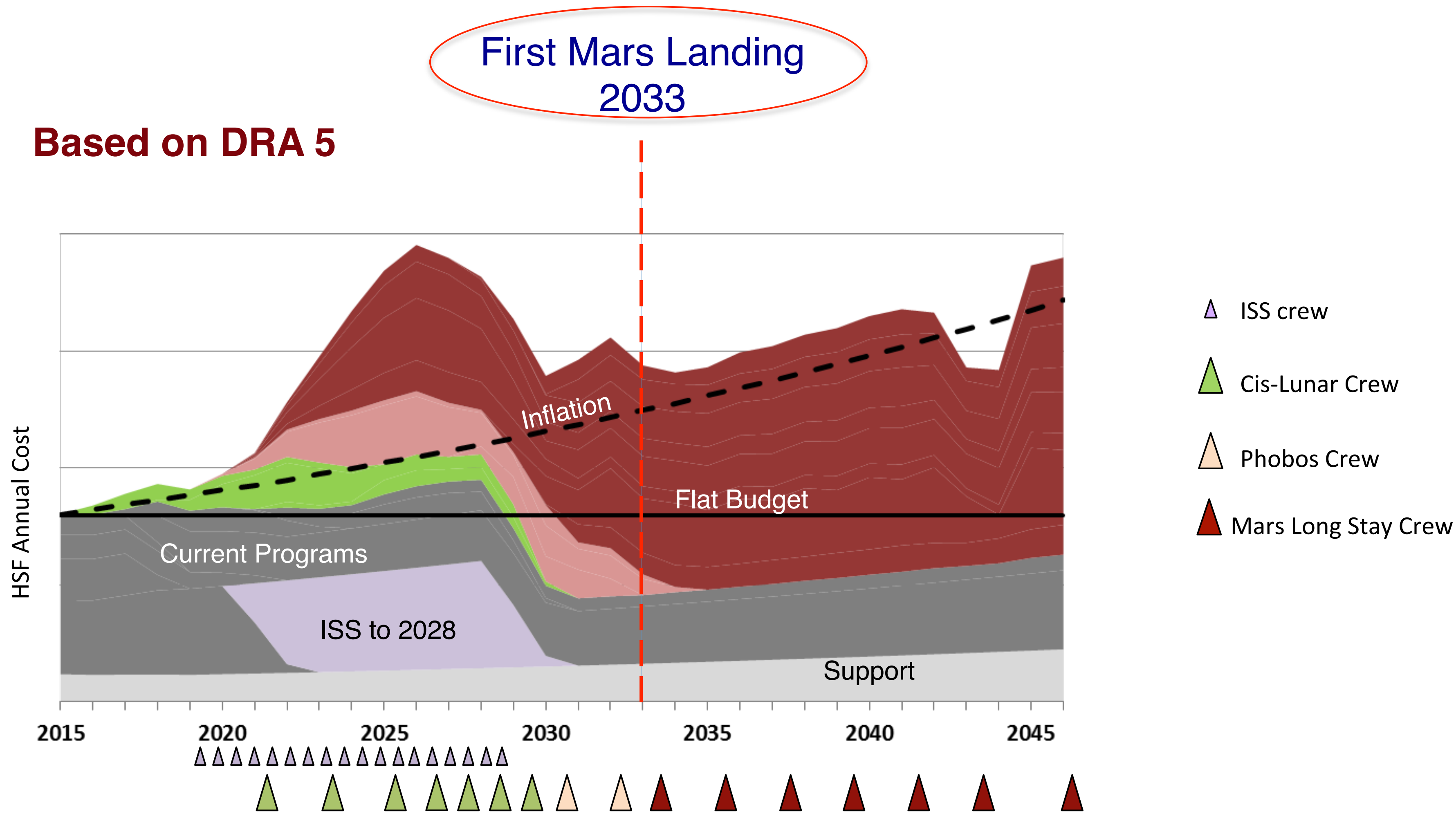
Threading Eye of the Needle

Two Competing Constraints Meet Head on

The Recent NRC Study

Schedule Driven Pathway

Based on DRA 5



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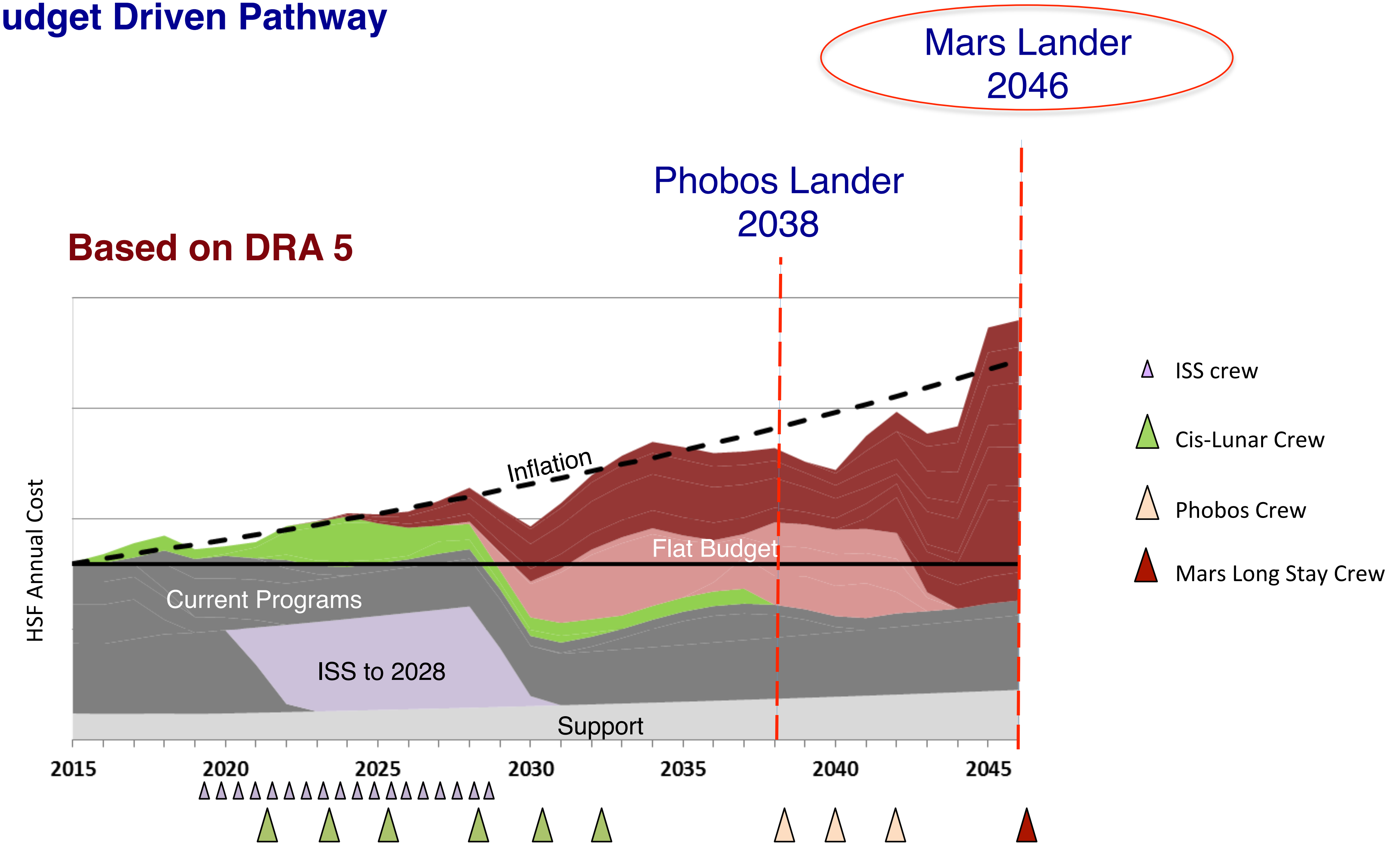
The Recent NRC Study

Budget Driven Pathway



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How Do You Stay Affordable

And Yet Deliver Engaging Missions Within Interest Horizon of Stakeholders?

Step-wise introduction of complexity at Mars

1. **Break up the Journey into Several Staggered Mission Campaigns.**
   - **First Campaign**: Mission to the Mars System (land on Phobos)
     - We have proposed ***limited*** testing at the Moon/cis-lunar space prior to the first campaign
   - **Second Campaign**: Short stay on the surface of Mars (24 days)
   - **Third Campaign**: Long stay on Mars (one year)
   - **Later**: Build up infrastructure toward a permanent stay
   - Each campaign builds on the heritage left behind from previous campaign and leaves a legacy for those coming after
2. **Minimal Architecture**
   - Relying on limited set of elements already built or planned by NASA and avoid complicated developments (such as nuclear thermal propulsion)

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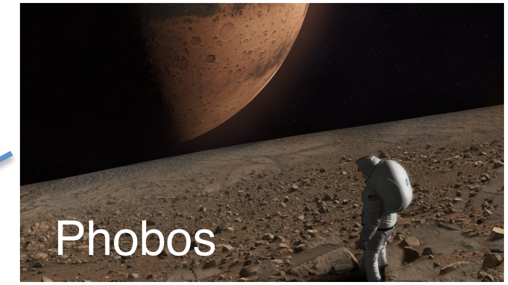
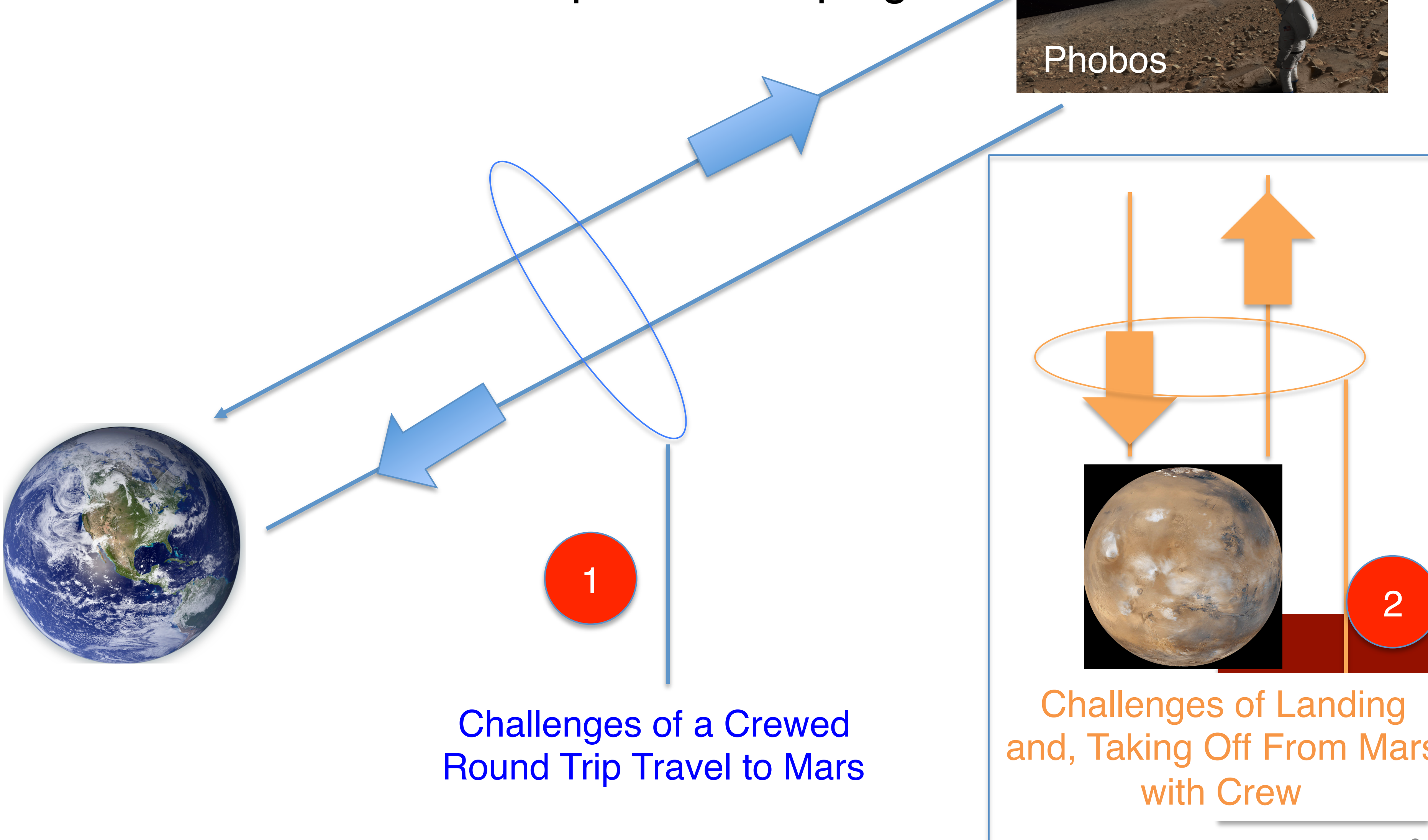
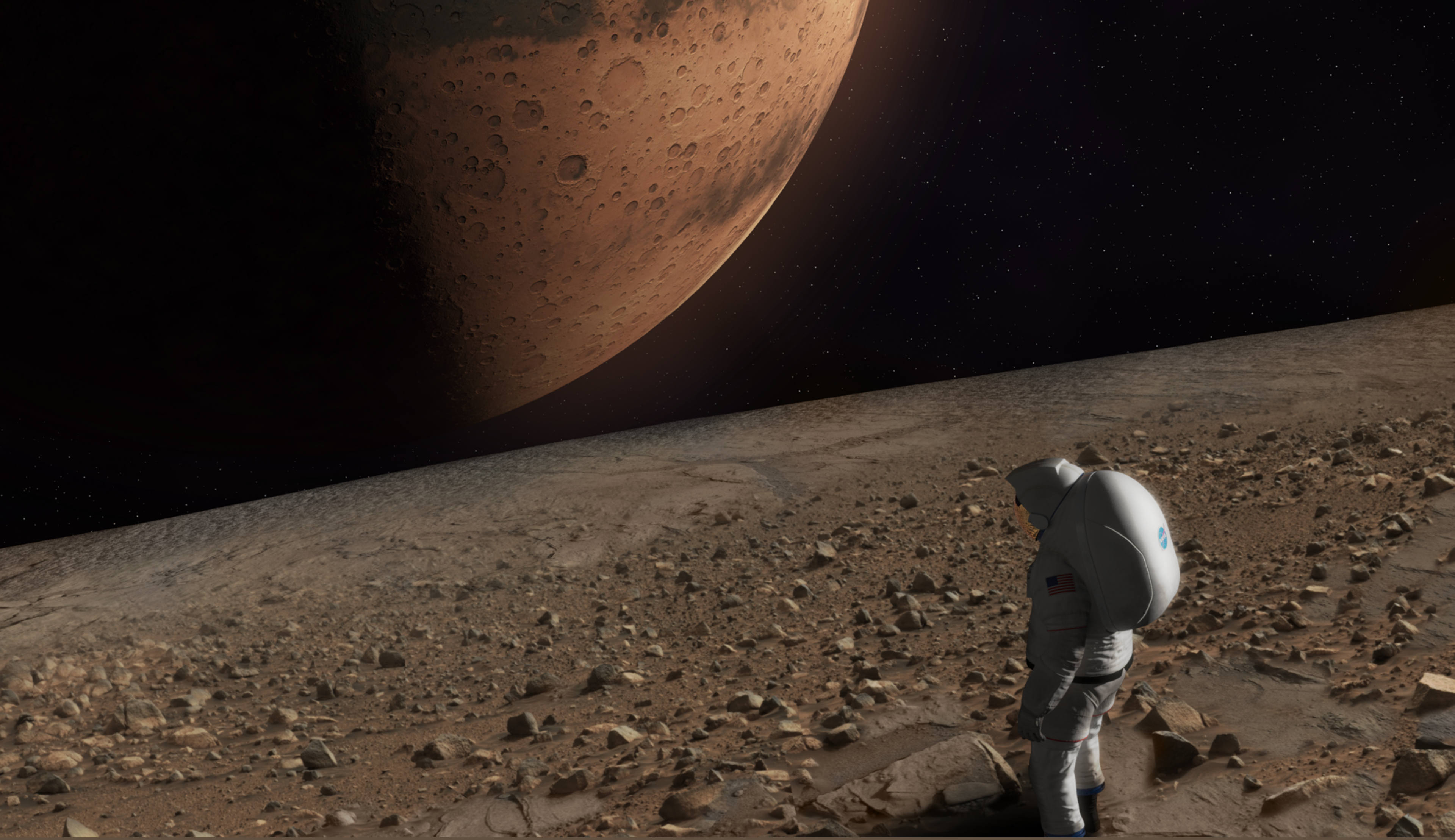
To spread the cost (required cash flow) and the risk, break up the challenges of crewed travel to Mars into **two** separate campaigns

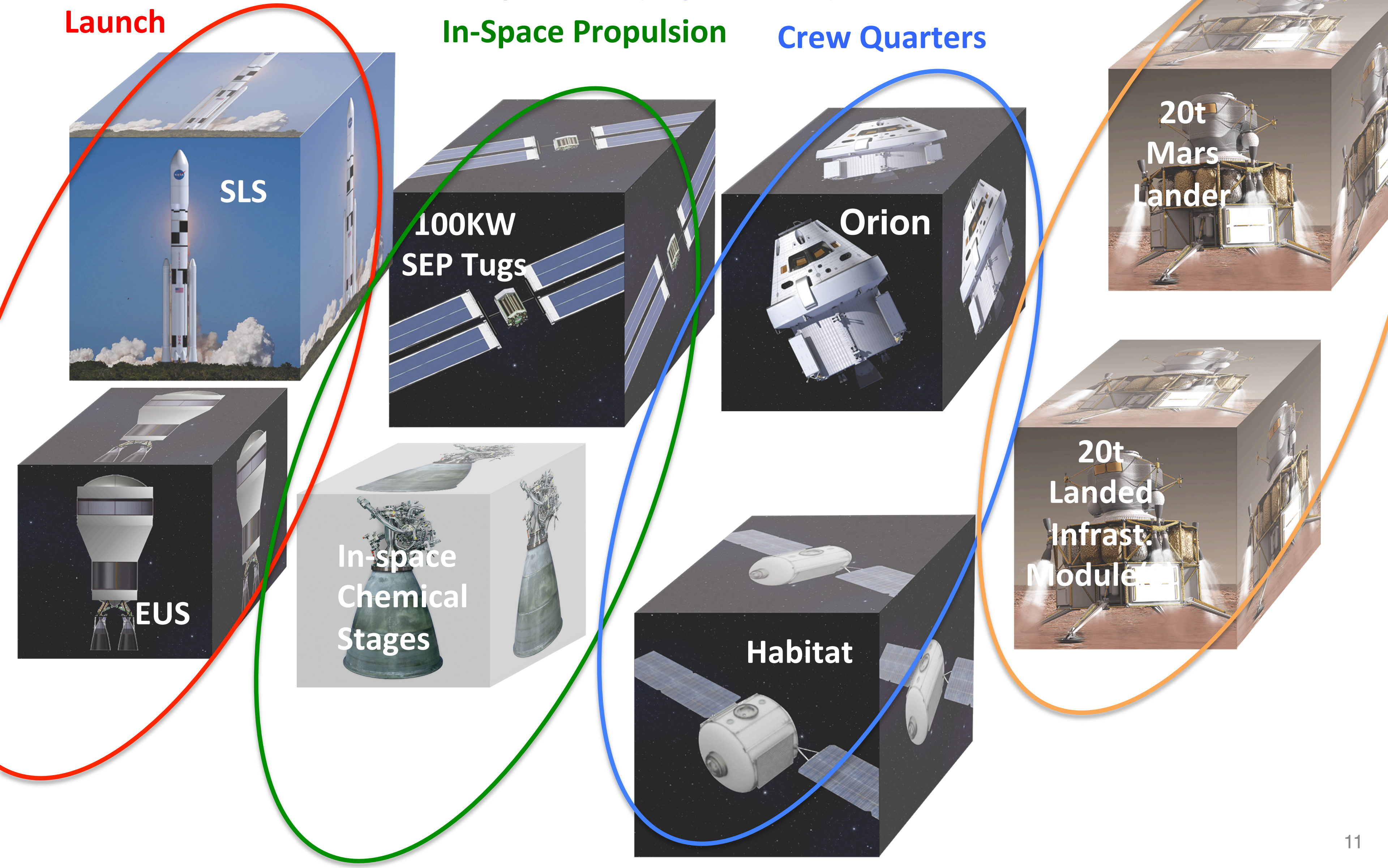




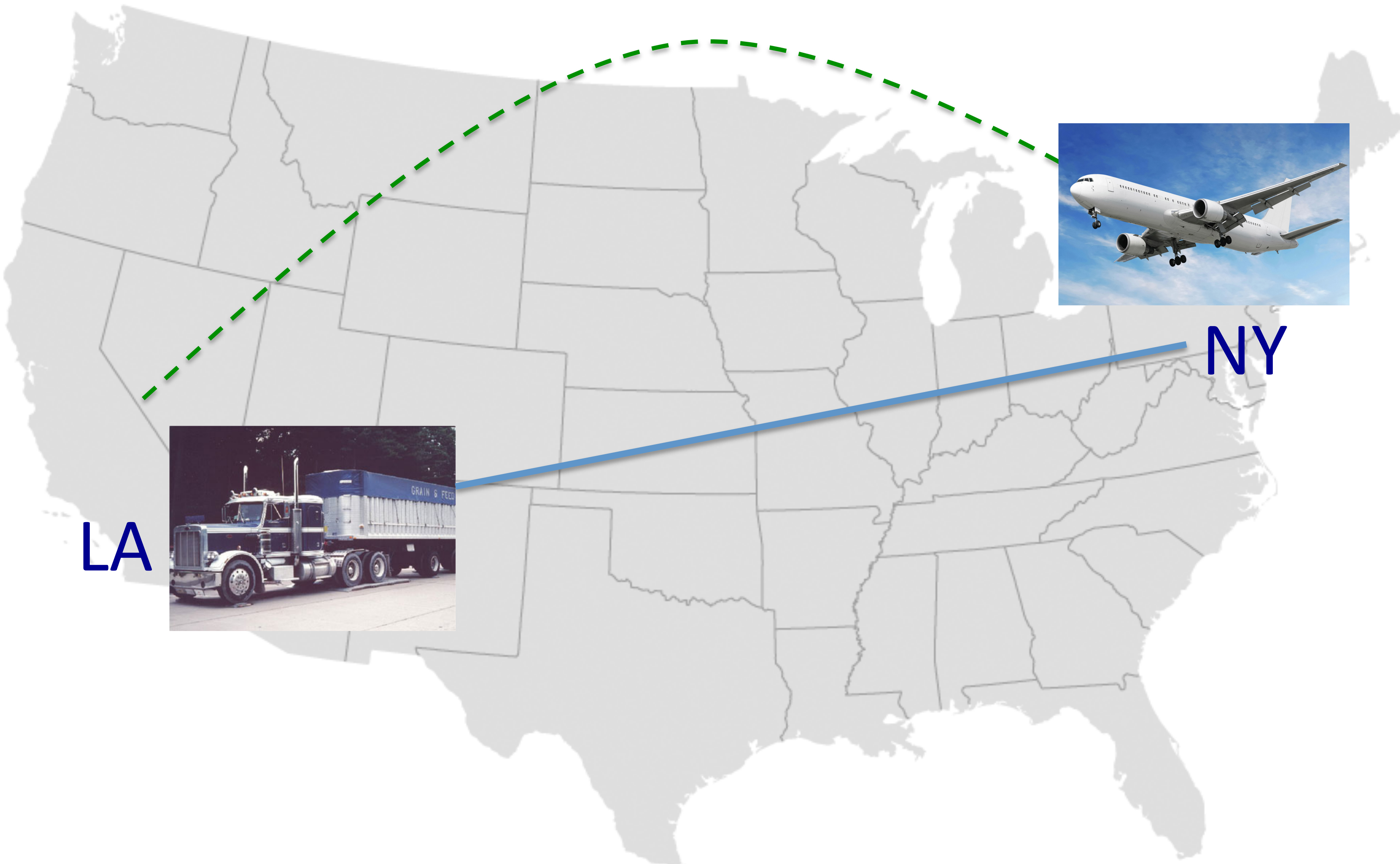


Mars as Seen from Phobos

Building Blocks of a Minimal Architecture



Pre-Positioning Assets



Increasing the Likelihood That It Can Be Implemented

- Mission architectures need to be checked for **affordability**
  - Mission costs need to be verified by a non-advocate third party
- For Journey to Mars to remain in the **interest horizon** of stakeholders, humans need to go to Mars system in the early 2030's
- Much can be learned from ISS in the next decade but NASA needs to start thinking about the **ISS end game** and repurposing those funds
- Gaining Experience in the **Moon/cis-lunar space** can be beneficial
  - However, the extent of activities should be weighed against delayed time table for human presence at Mars
- A coherent **long-term strategy** (beyond the 5-year budget cycle) needs to be articulated
  - Engage the would be international partners
  - Outline opportunities for private sector participation
  - Keep other stakeholders interested

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Mission to Mars Orbit and Phobos

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Phobos Landing Concept
Attributes of the Campaign

- Precursor to Mars landing campaign
- Proves out method for getting to Mars orbit and back
- Uses 4 SLS launches
- Pre-position assets in Mars system with SEP tugs prior to crew arrival
- Round trip crew mission ~2 ½ years; ~300 days at Phobos

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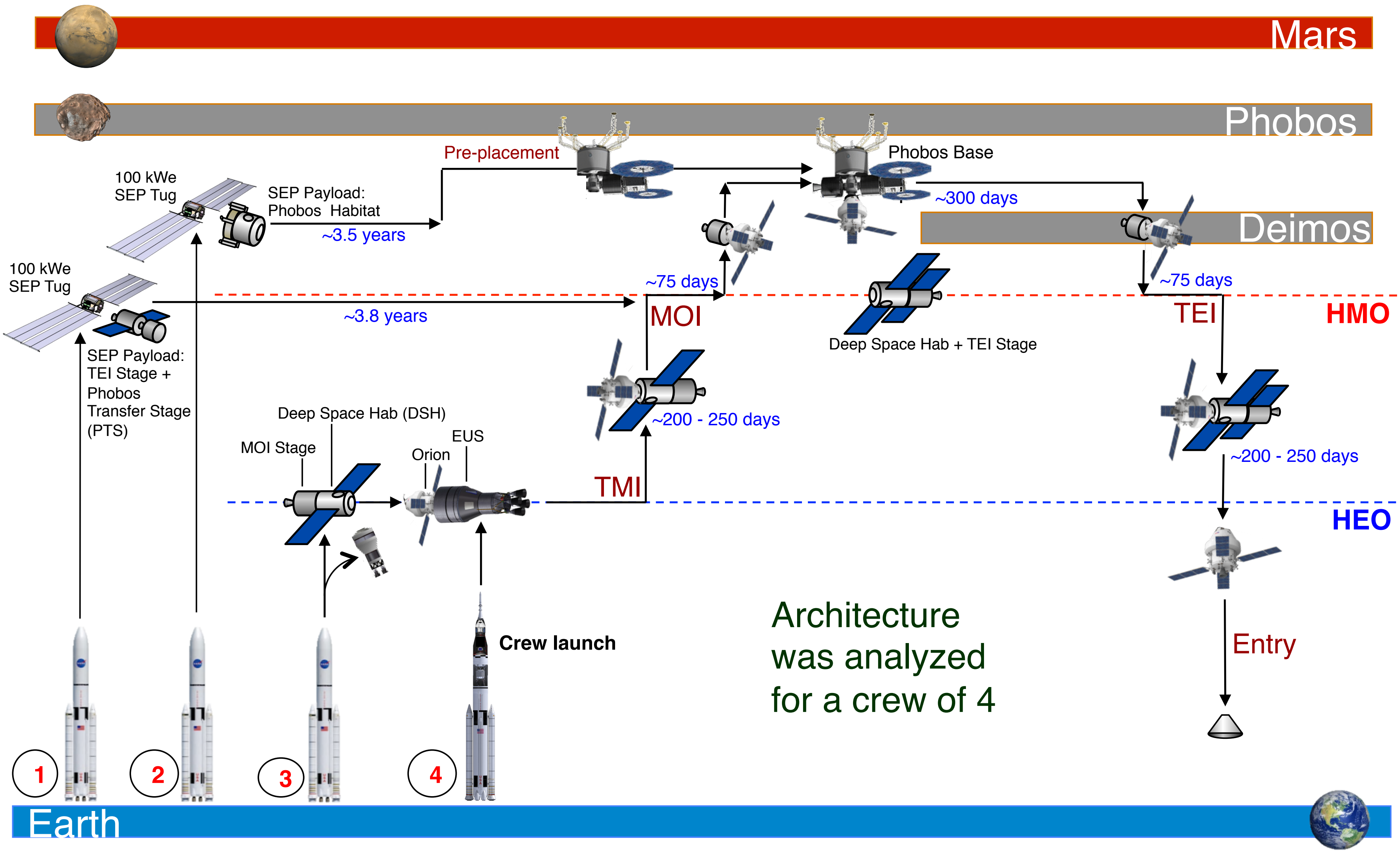
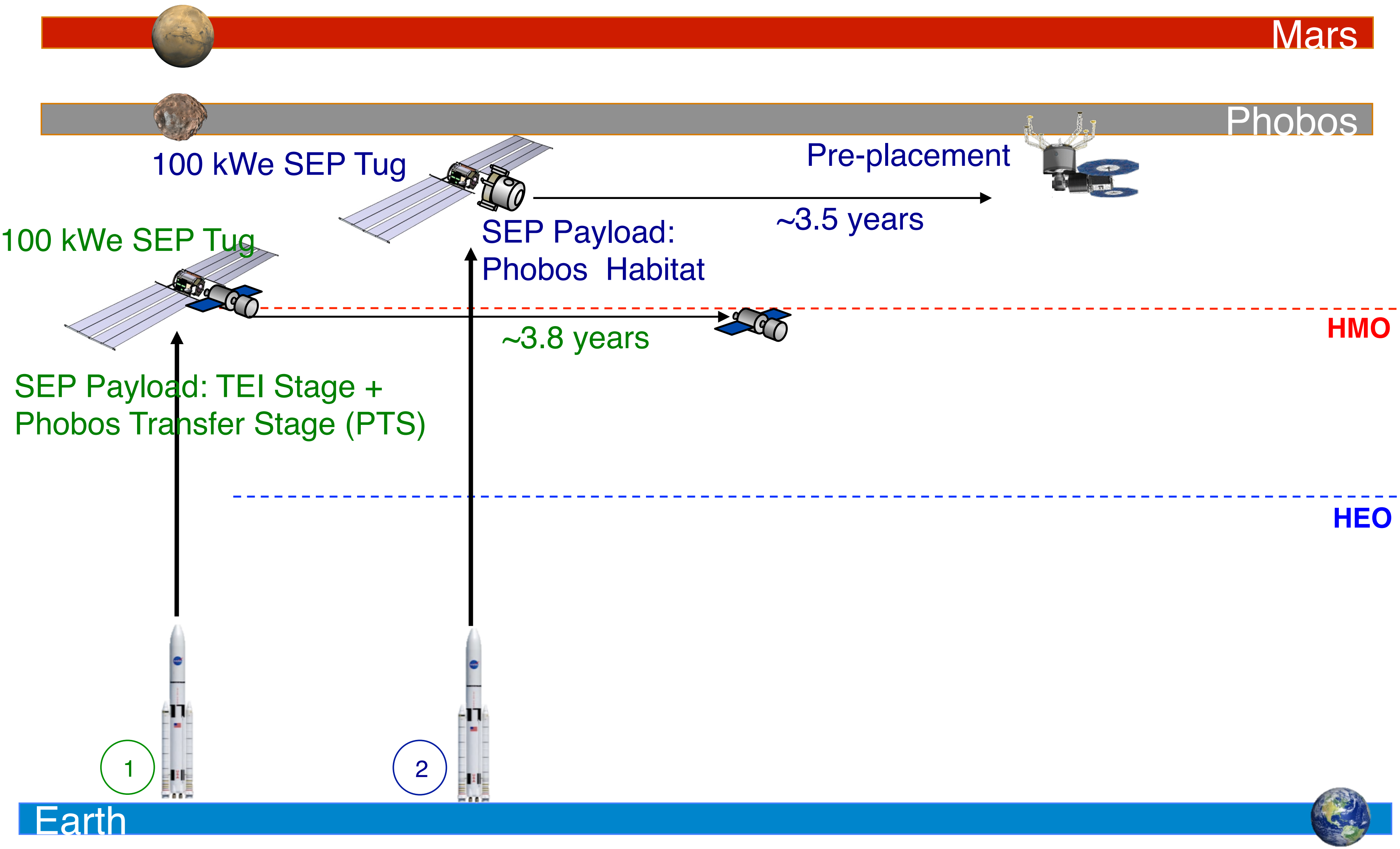
Overall Architecture Concept

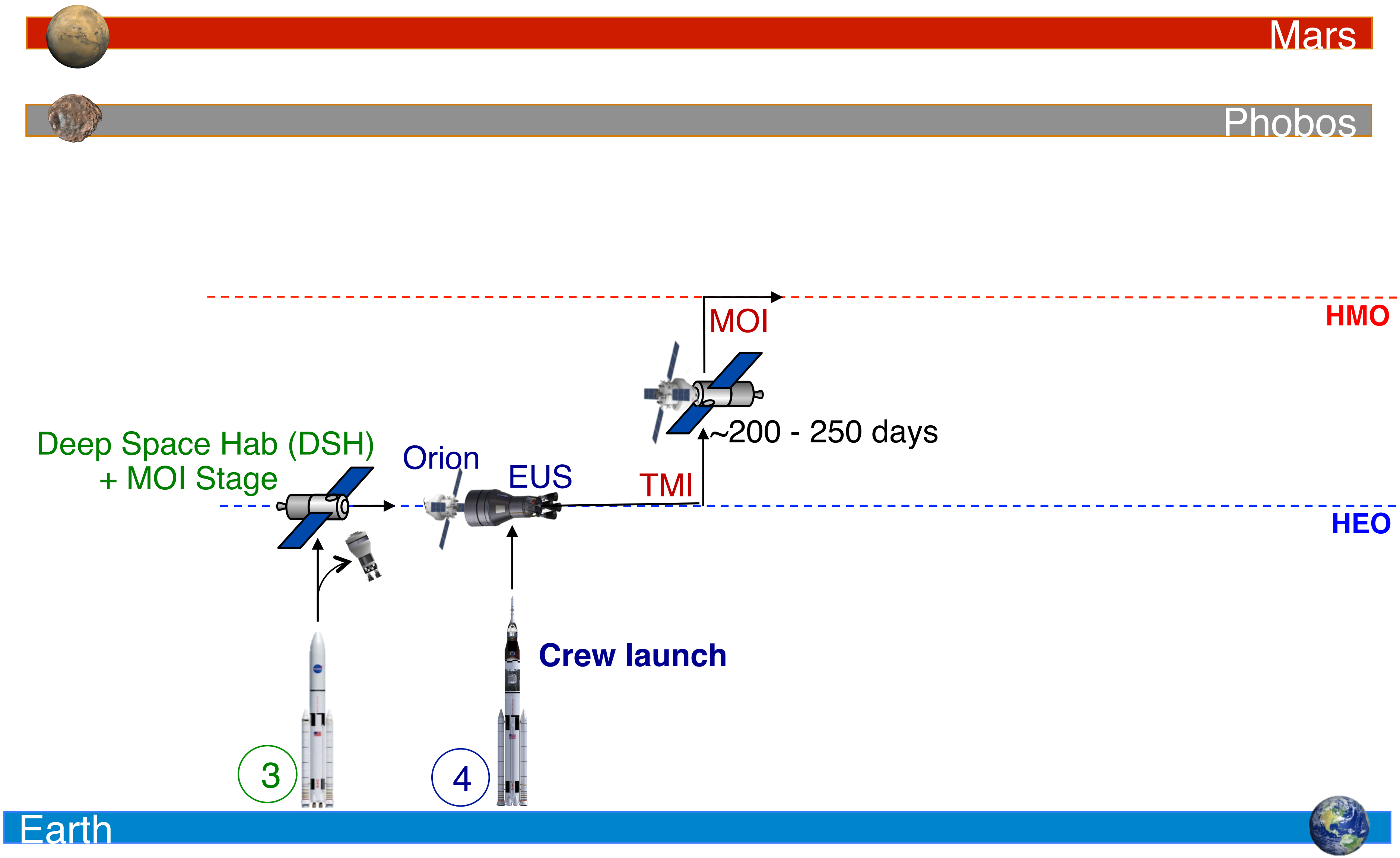
4 SLS Launches



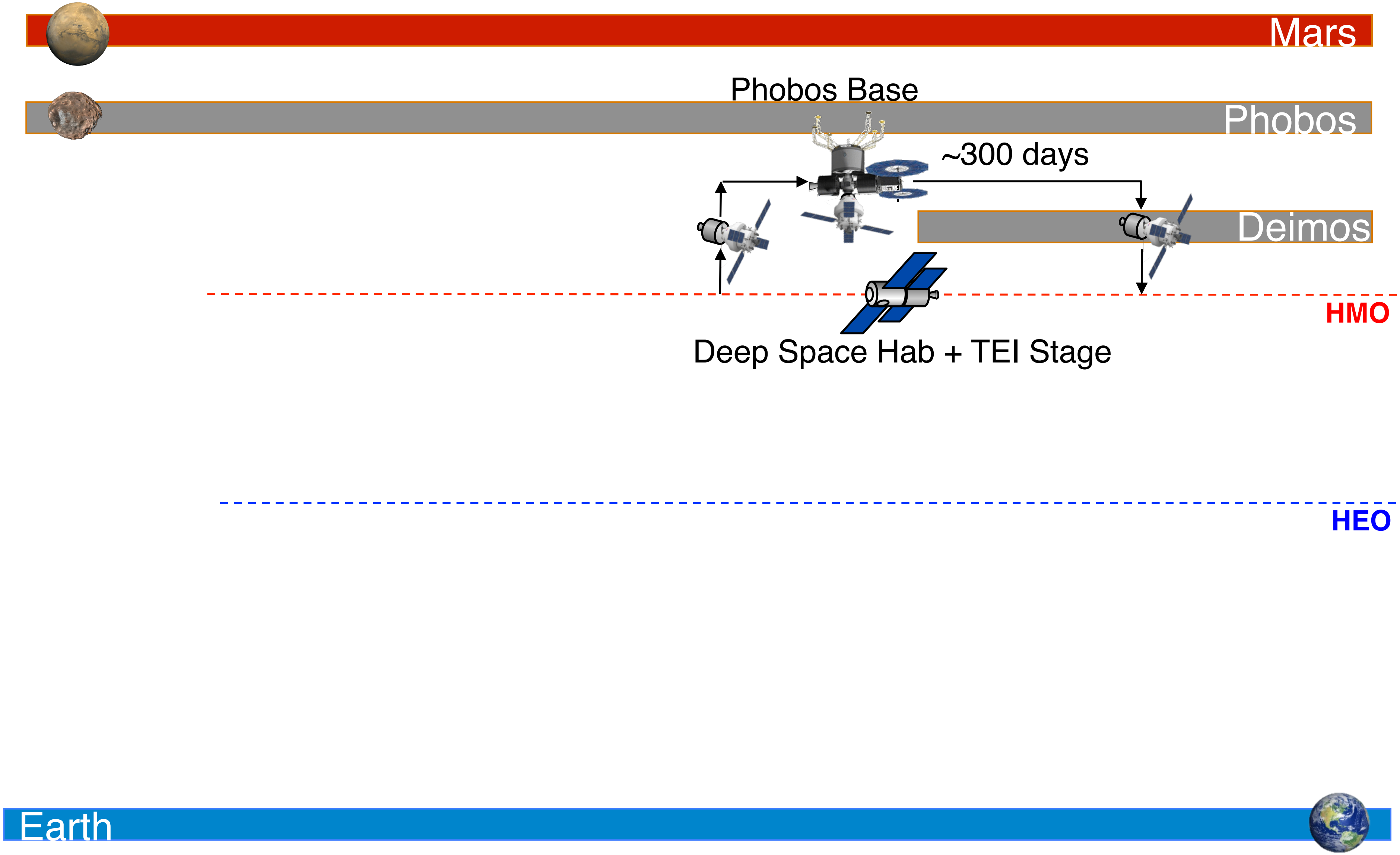
Getting Cargo to HMO and Phobos



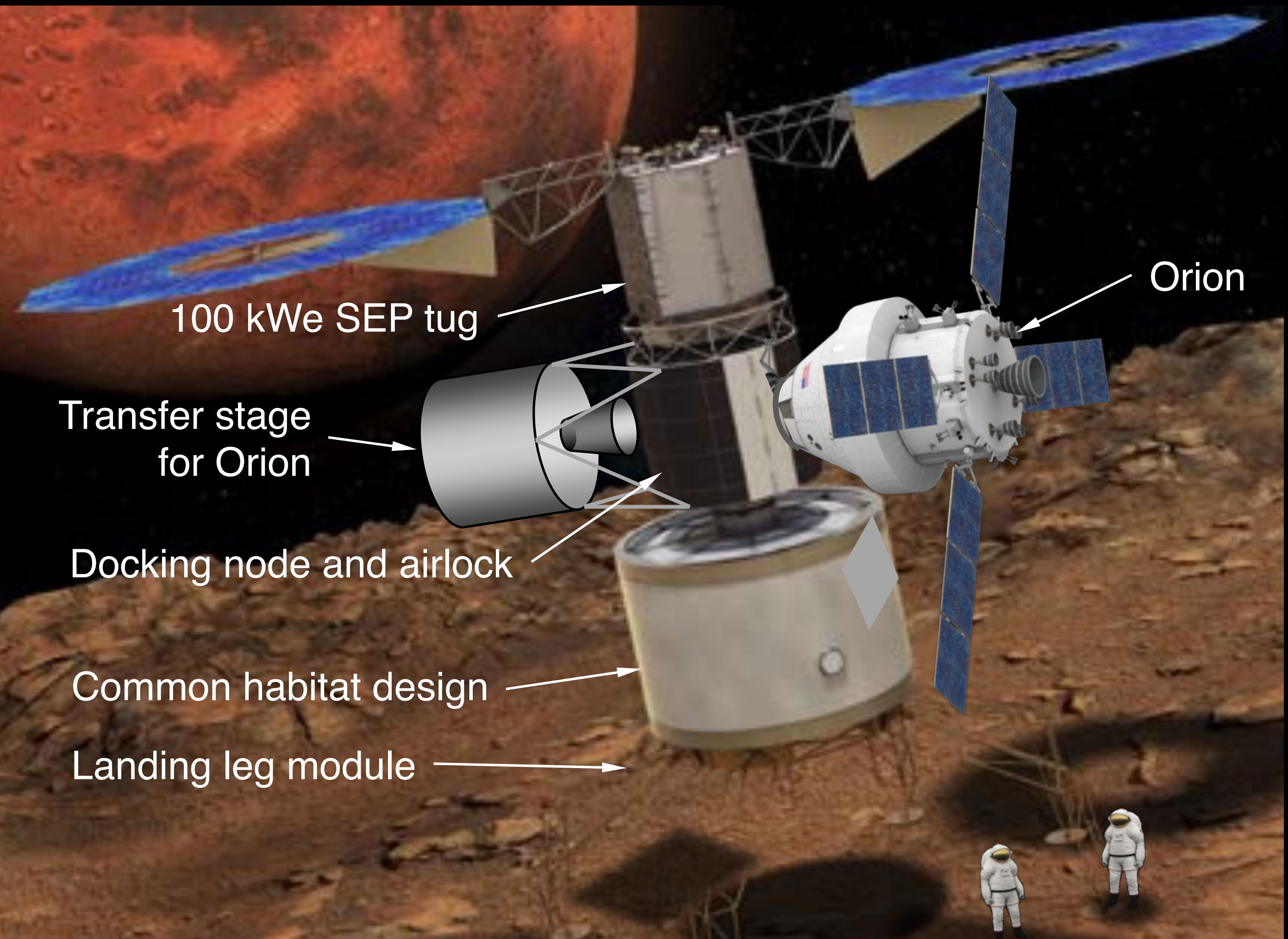
Getting Crew to HMO



Getting Crew from HMO to Phobos and Back to HMO



Phobos Base Concept



- Supports a crew of 4
- Could be relocated to different sites
- Could be re-used by future crews

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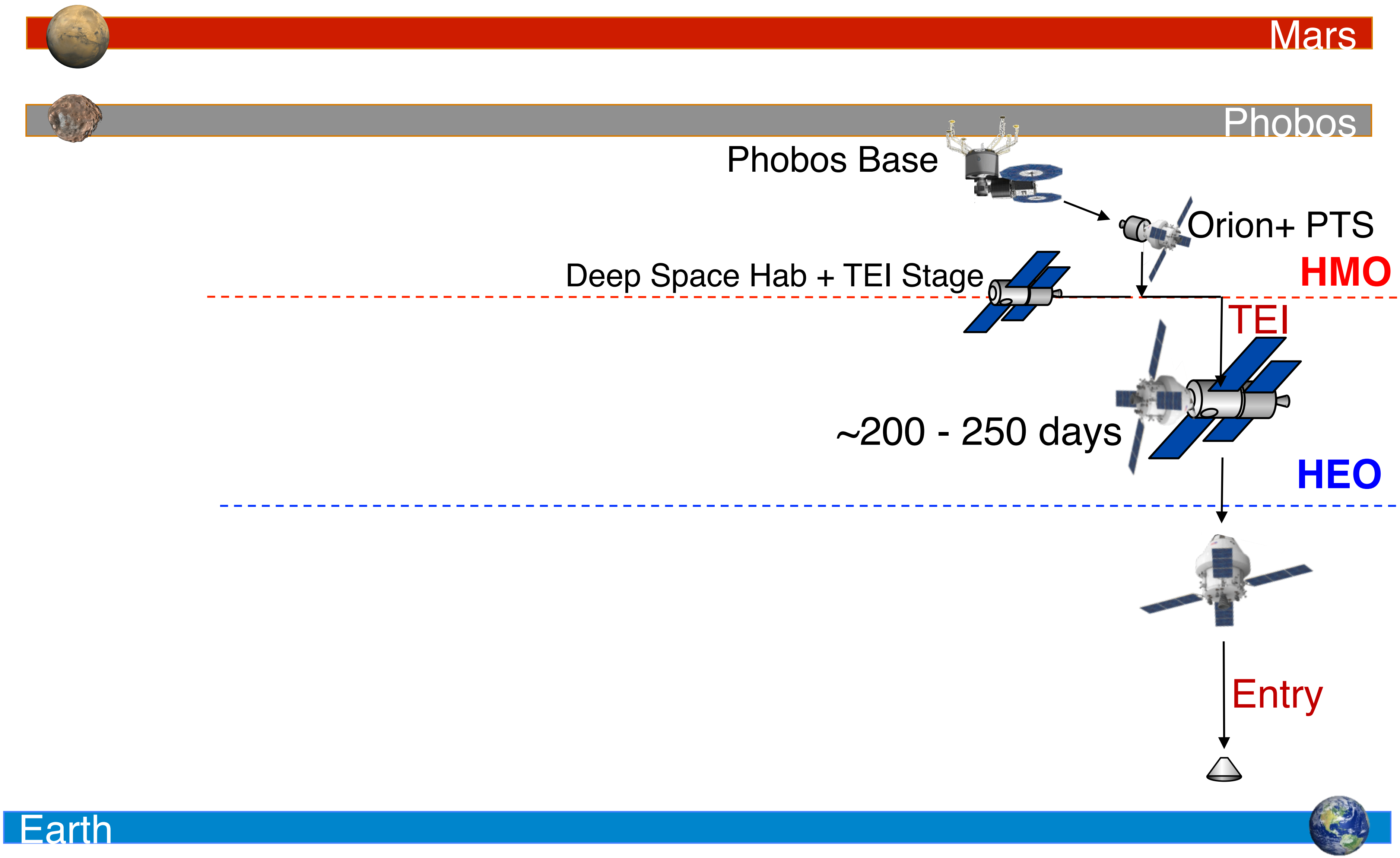
Coming Back to Earth



Mars Short-Stay Surface Campaign

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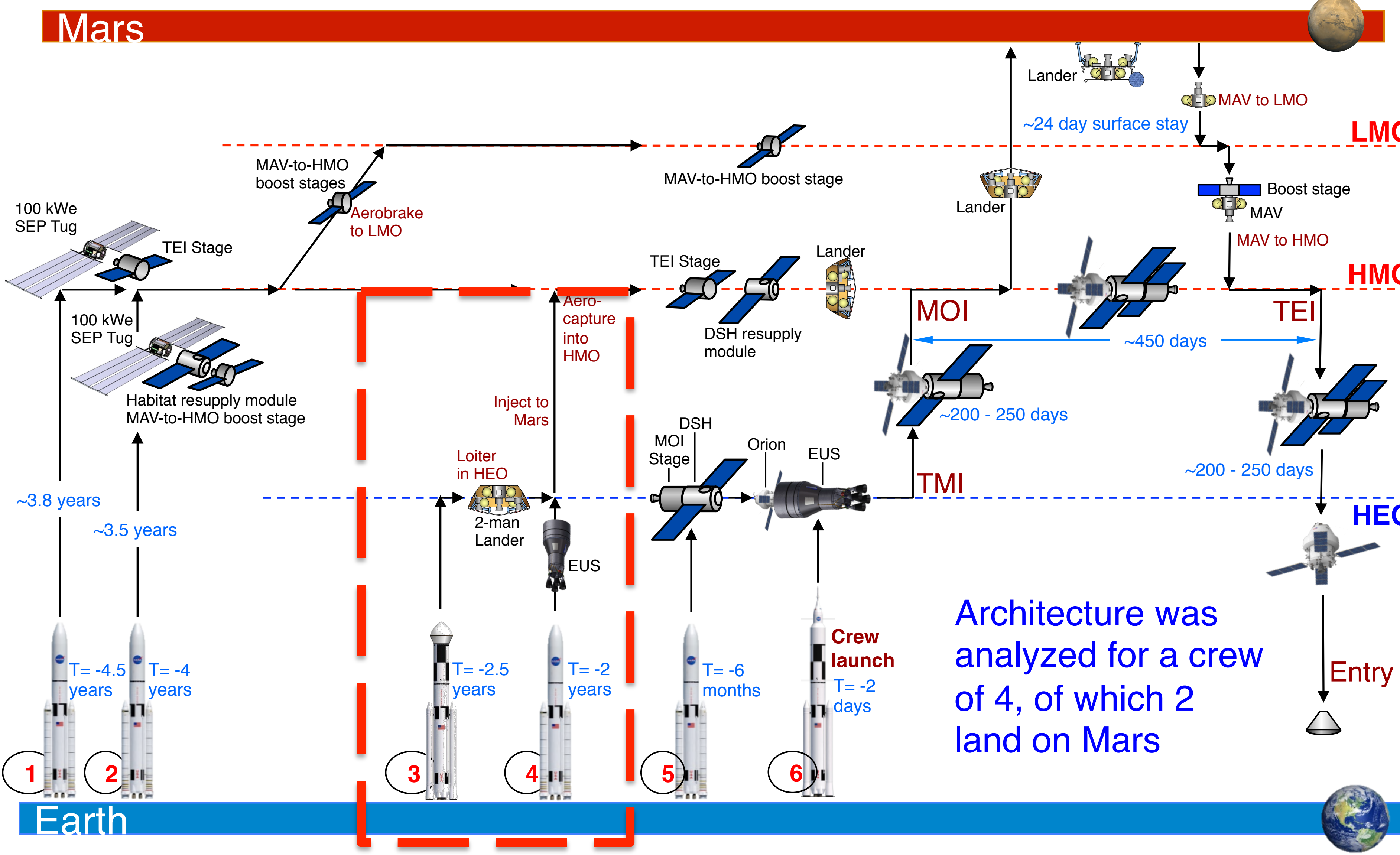
24-day Mars Surface Stay

Attributes of the Campaign

- Architecture re-uses the Phobos approach for getting crew to HMO and back to Earth (already tested in 2033)
- The lander requires 2 additional SLS launches relative to Phobos mission, bringing total SLS launches to 6
  - Lander entry mass ~75t with 23 t useful landed mass
  - Crew of 2 to the surface, 24-day stay
- Lift off from Mars surface is achieved through a two-step ascent to High Mars Orbit (HMO)
  - MAV: Surface to Low Mars Orbit (LMO), then boosted to HMO
  - Minimizes the MAV propellant load to enable 23 t lander

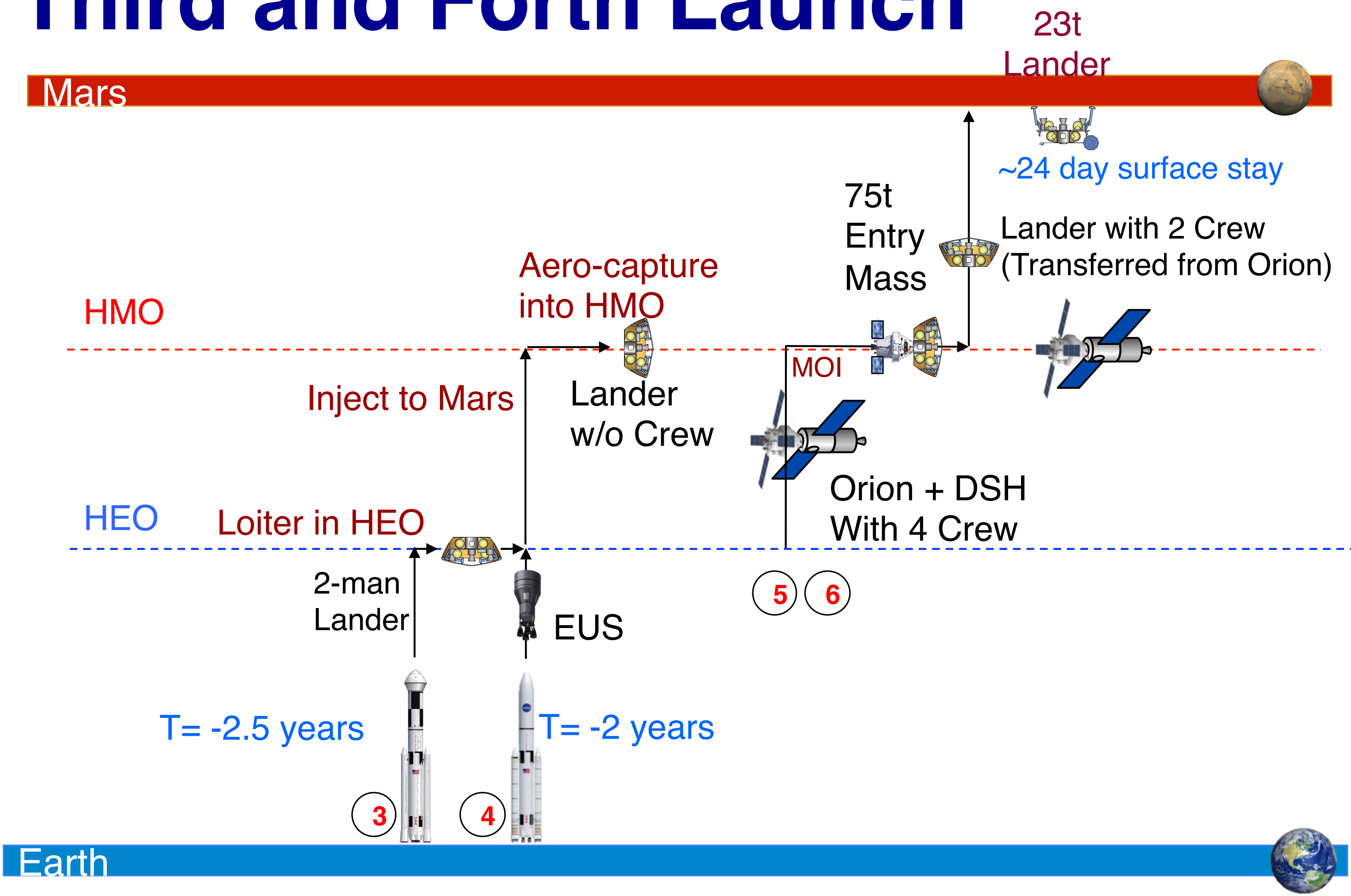
Short-stay Surface Concept

24-Day Surface Stay; Crew of 2; 6 SLS Launches

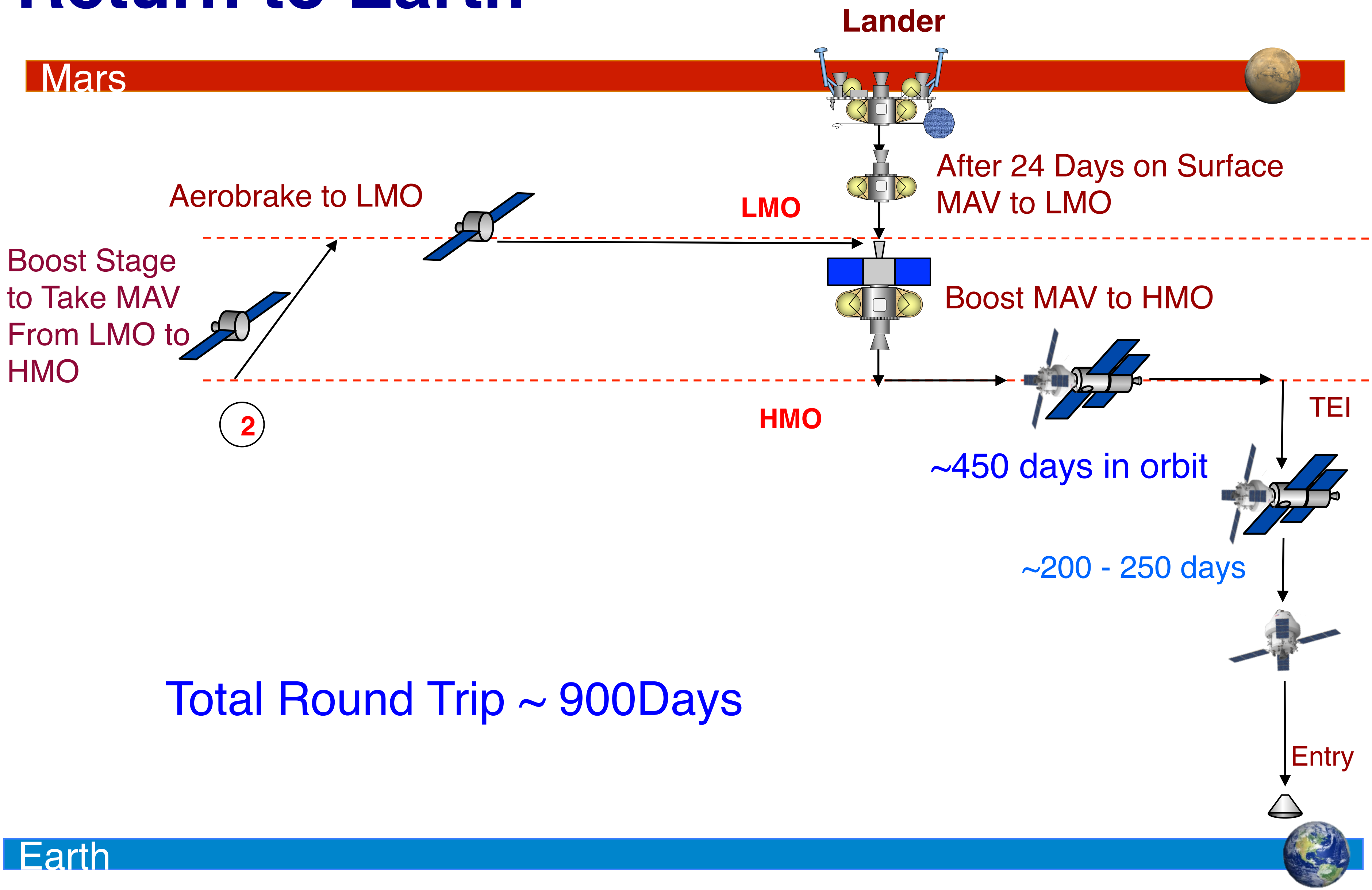


Architecture was analyzed for a crew of 4, of which 2 land on Mars

Third and Forth Launch

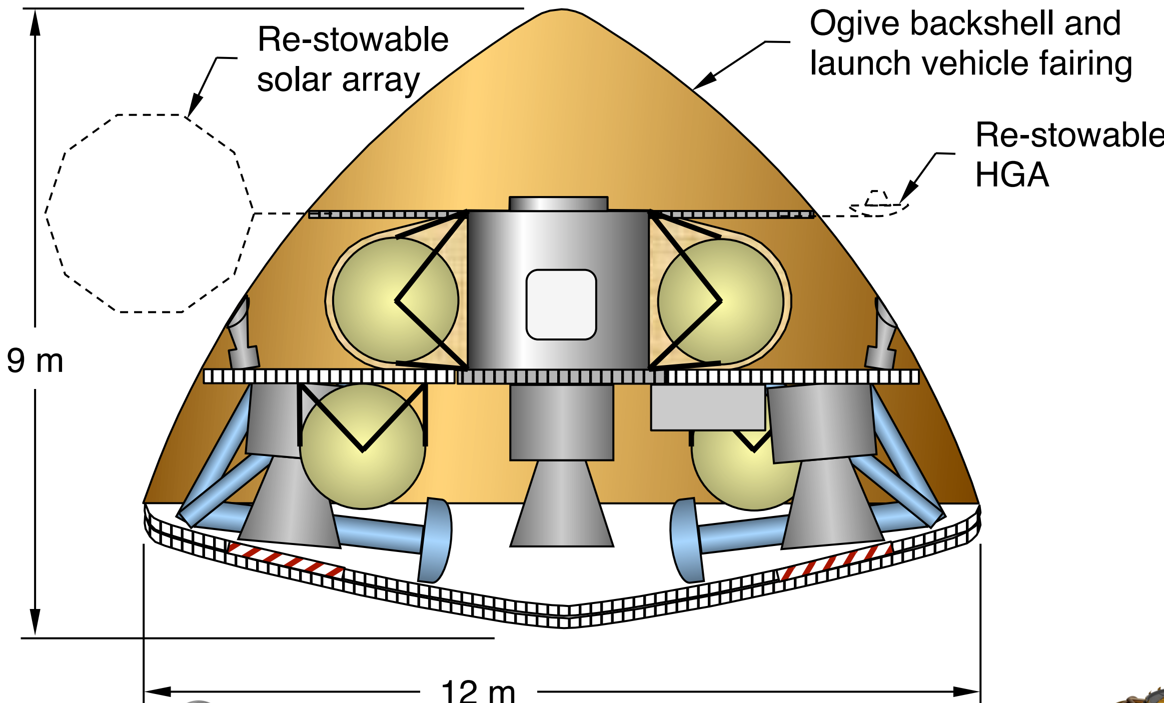


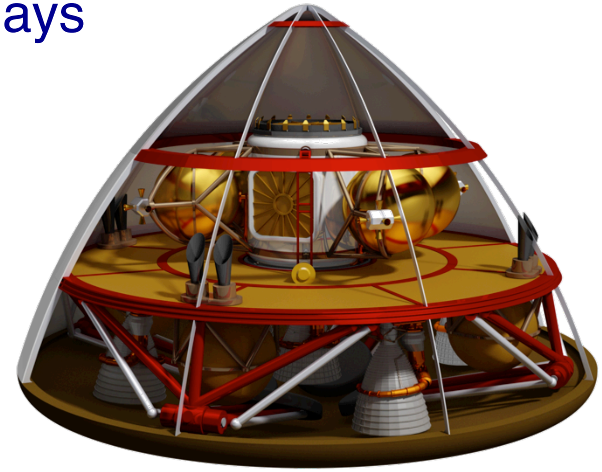
Return to Earth

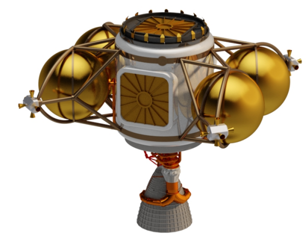


Descent/Ascent Vehicle (DAV)

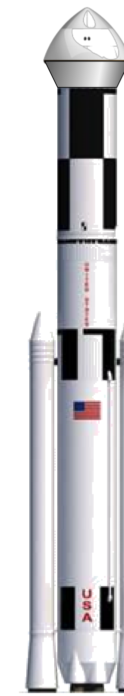
Can support crew of 2 for 28 days, or crew of 4 for 6 days

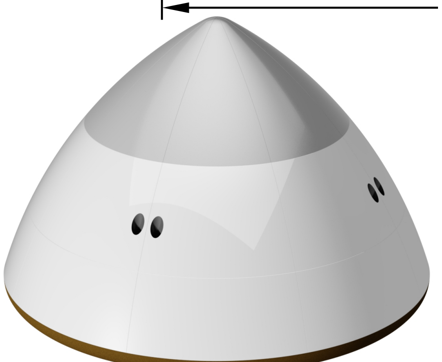






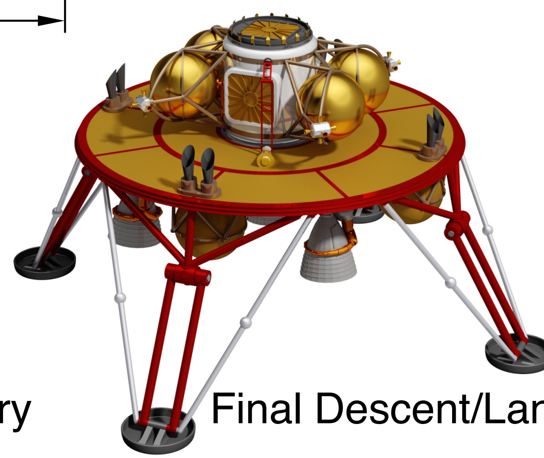
MAV Ascent





Launch

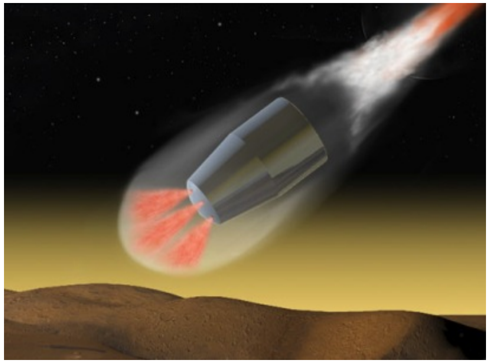
Cruise/Crew Transfer/Entry

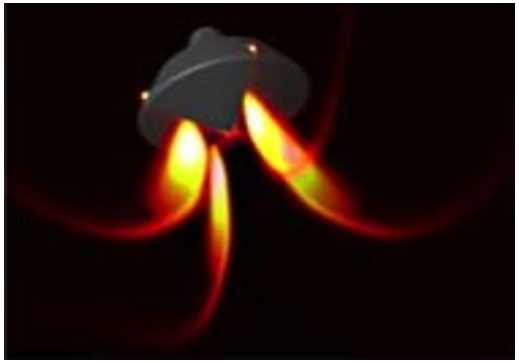


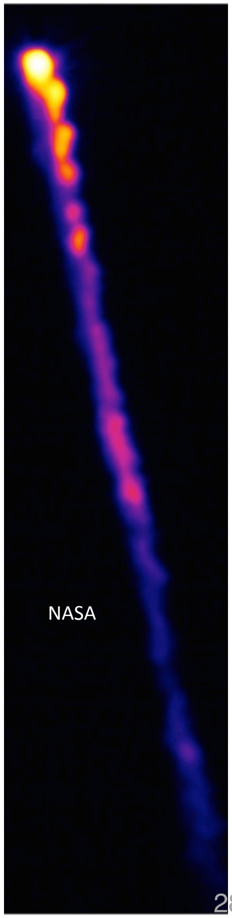
Final Descent/Landing

Supersonic Retro-Propulsion (SRP)

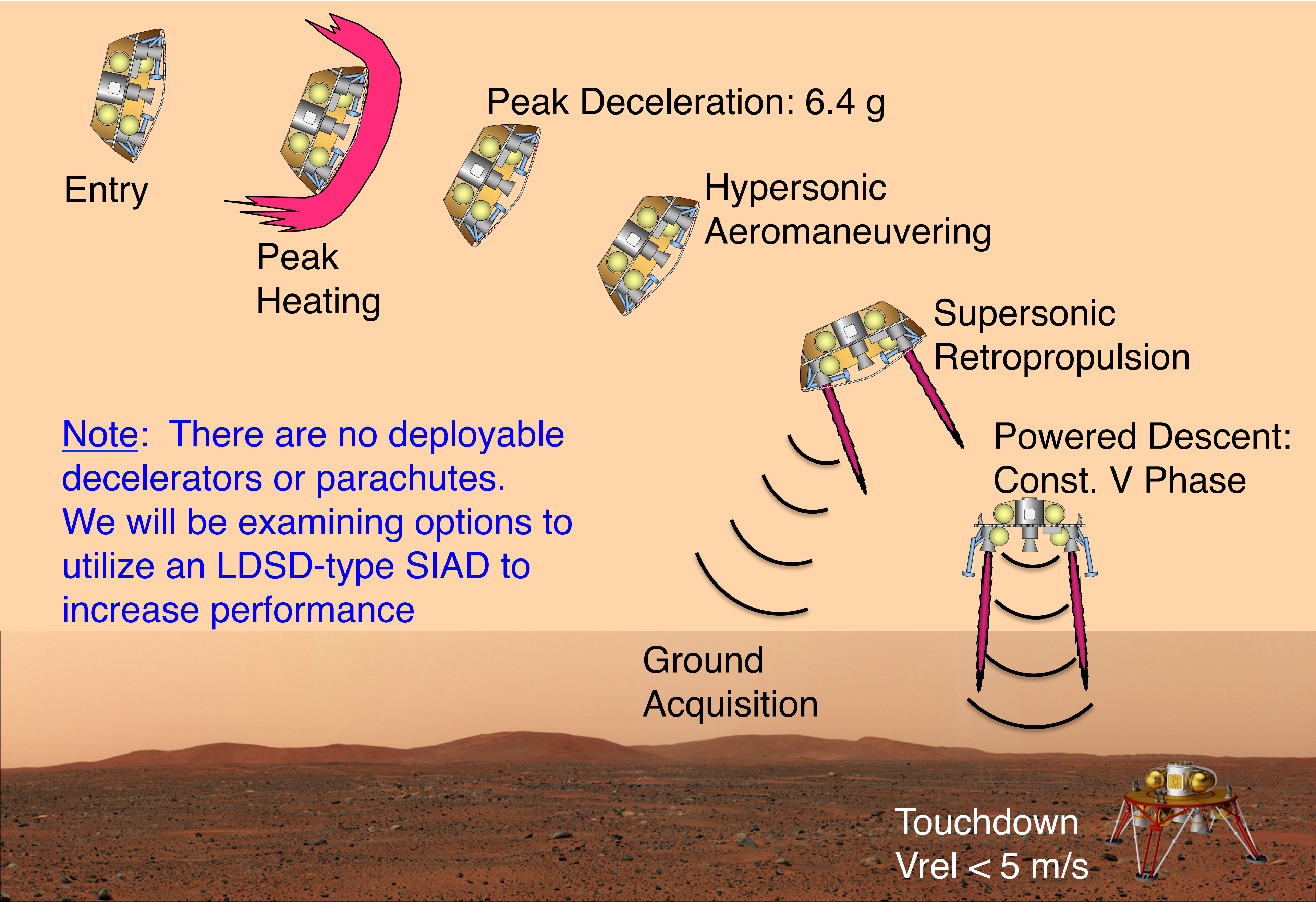
- Mars landers to date have used subsonic retro-propulsion
- Analyses have indicated the need for SRP for landing large payloads on Mars
- CFD analysis and wind tunnel tests have been performed, and now SRP data utilizing actual flight data has become available from Space X Falcon 9 stage recovery flights
  - 7 flights have been conducted with a portion of the flight regime being analogous to Mars atmospheric conditions





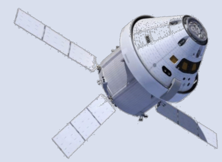
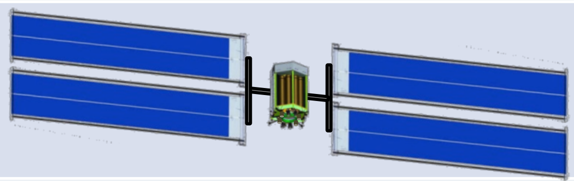
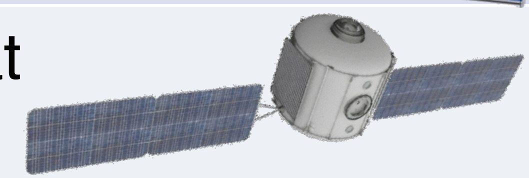
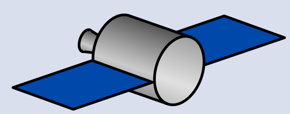
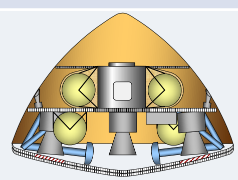


EDL Concept for Blunt Body Mars Lander



Note: There are no deployable decelerators or parachutes. We will be examining options to utilize an LDSD-type SIAD to increase performance

Six Vehicles to Enable Crewed Missions to Mars Surface (Short Stay)

Vehicles		# Vehicles per Mission
Orion		1
SLS		6
SEP Tug		2
Deep Space Habitat		2
In-Space Chemical Propulsion Stages		3
Mars Lander		1

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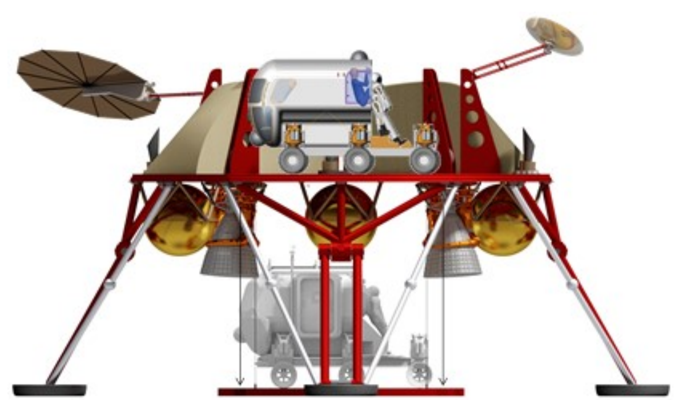
One-Year Surface Mission

10 SLS Launches

- Builds on the short-stay architecture but adds two additional landers bringing the total to three landers
  - Four additional SLS launches (2 per lander) are needed bringing total launches to 10 SLS
  - One lander carries a crew of 4 to the surface
  - One lander will carry the habitat and the other lander a pressurized rover and other supplies
- Ascent stage already fueled to lift crew of 4 to the LMO and then boosted to HMO



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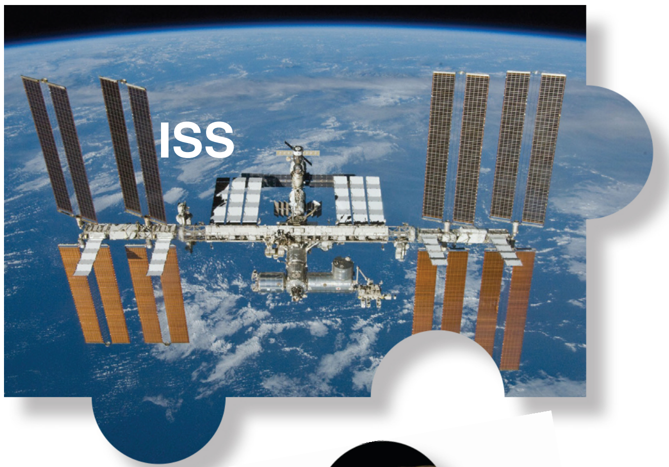
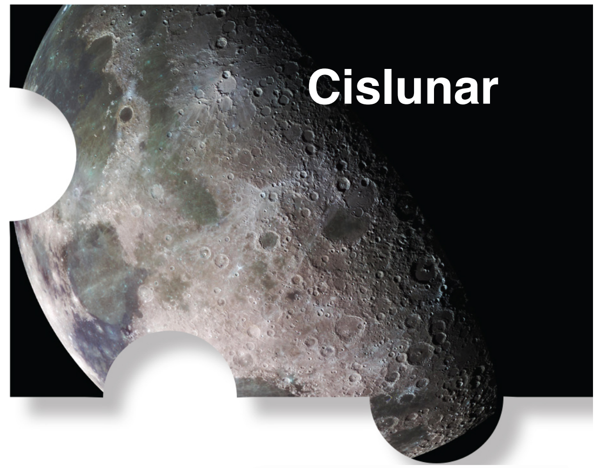
The Integrated Program

Fitting Together the Puzzle Pieces





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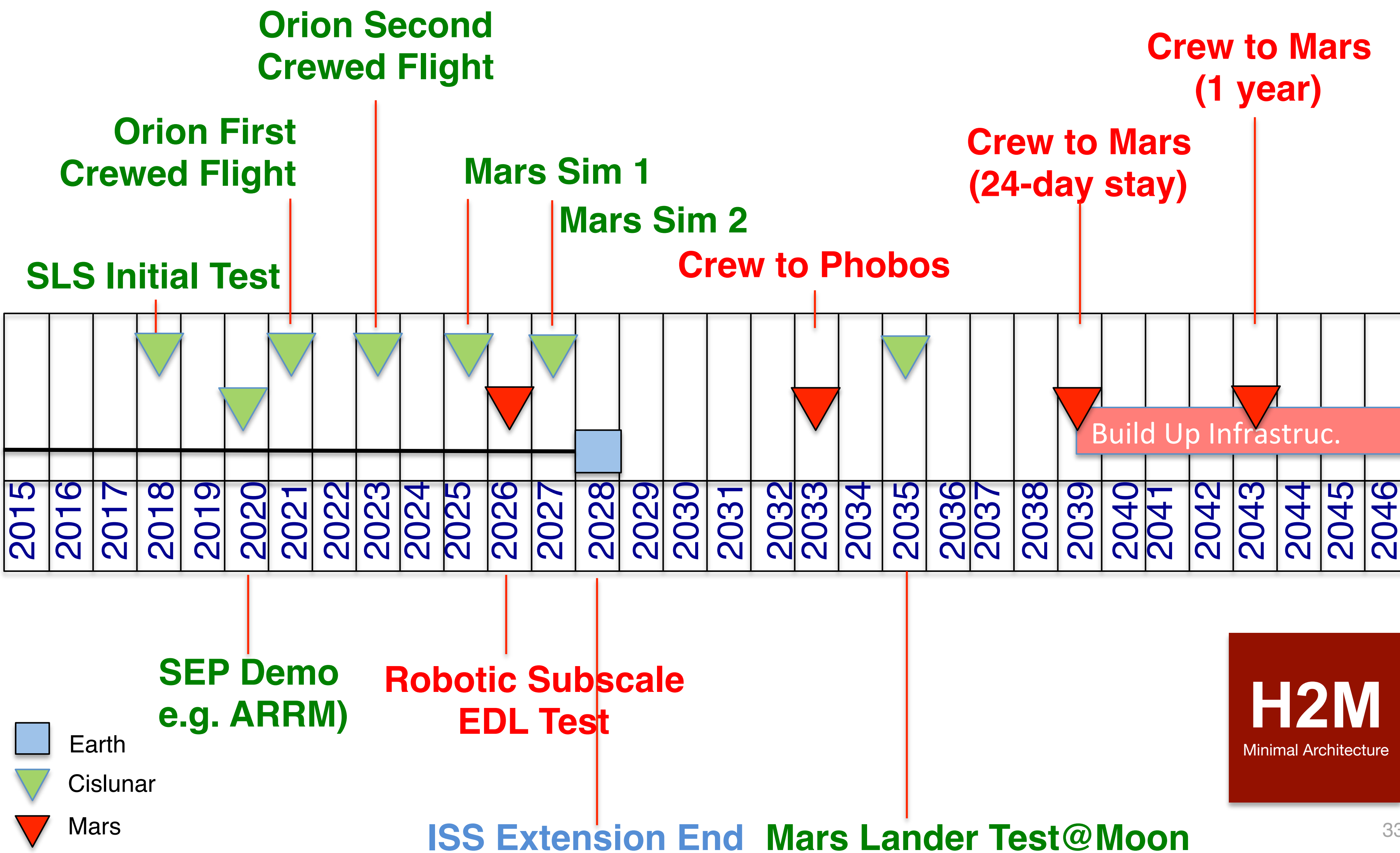
Notional Timeline



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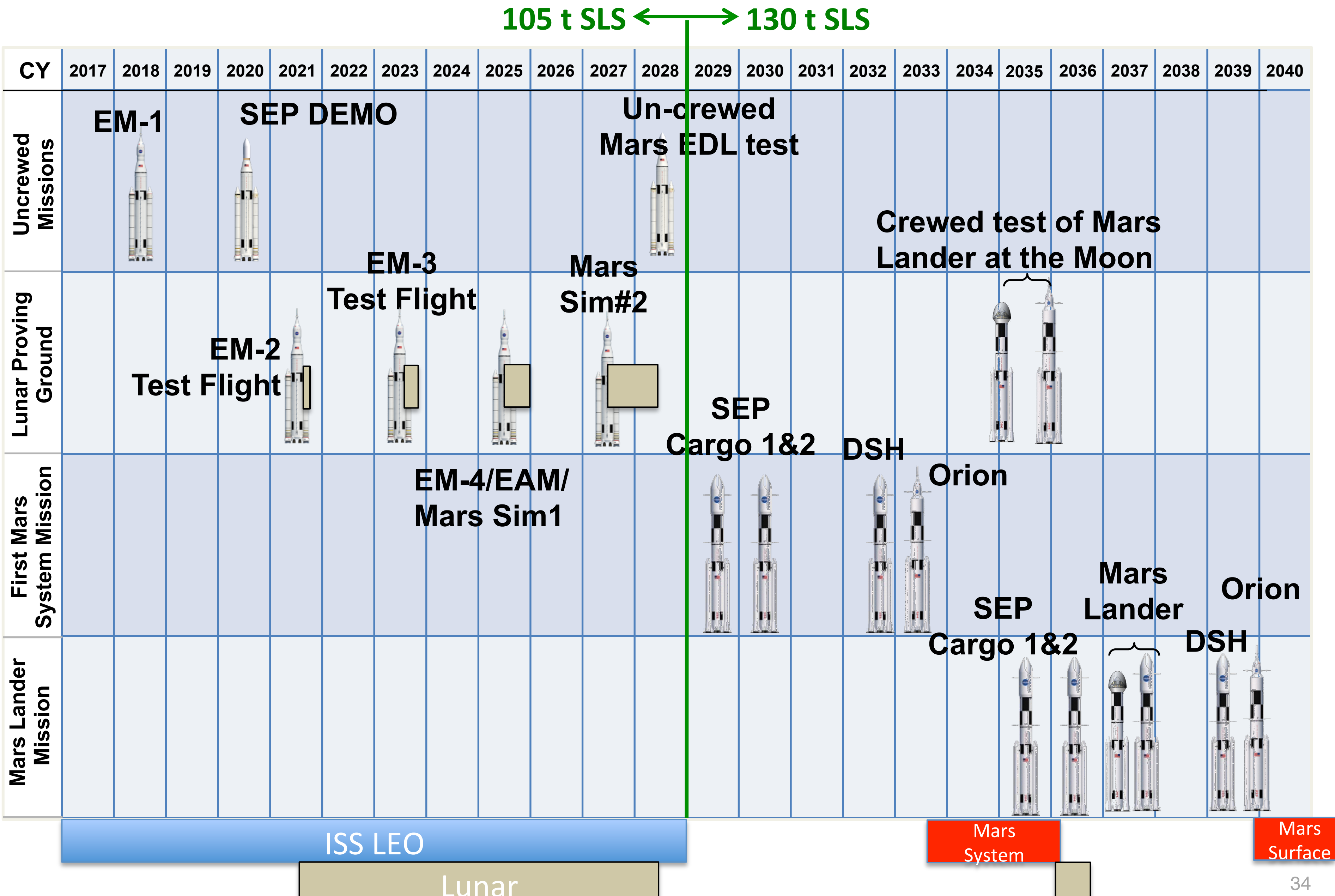
Notional SLS Flight Manifest



Cost "Sanity Check"

- Aerospace Corporation did the first-look cost assessment
- The cost estimating is based on models and analogy
  - Used model developed for NRC Pathways to Exploration study
  - As technical concepts mature, grassroots rather than model-based cost assessments should be performed for budget commitment
- Aerospace's assessment suggests that meeting the Study Team's self-imposed cost constraint is plausible

H2M
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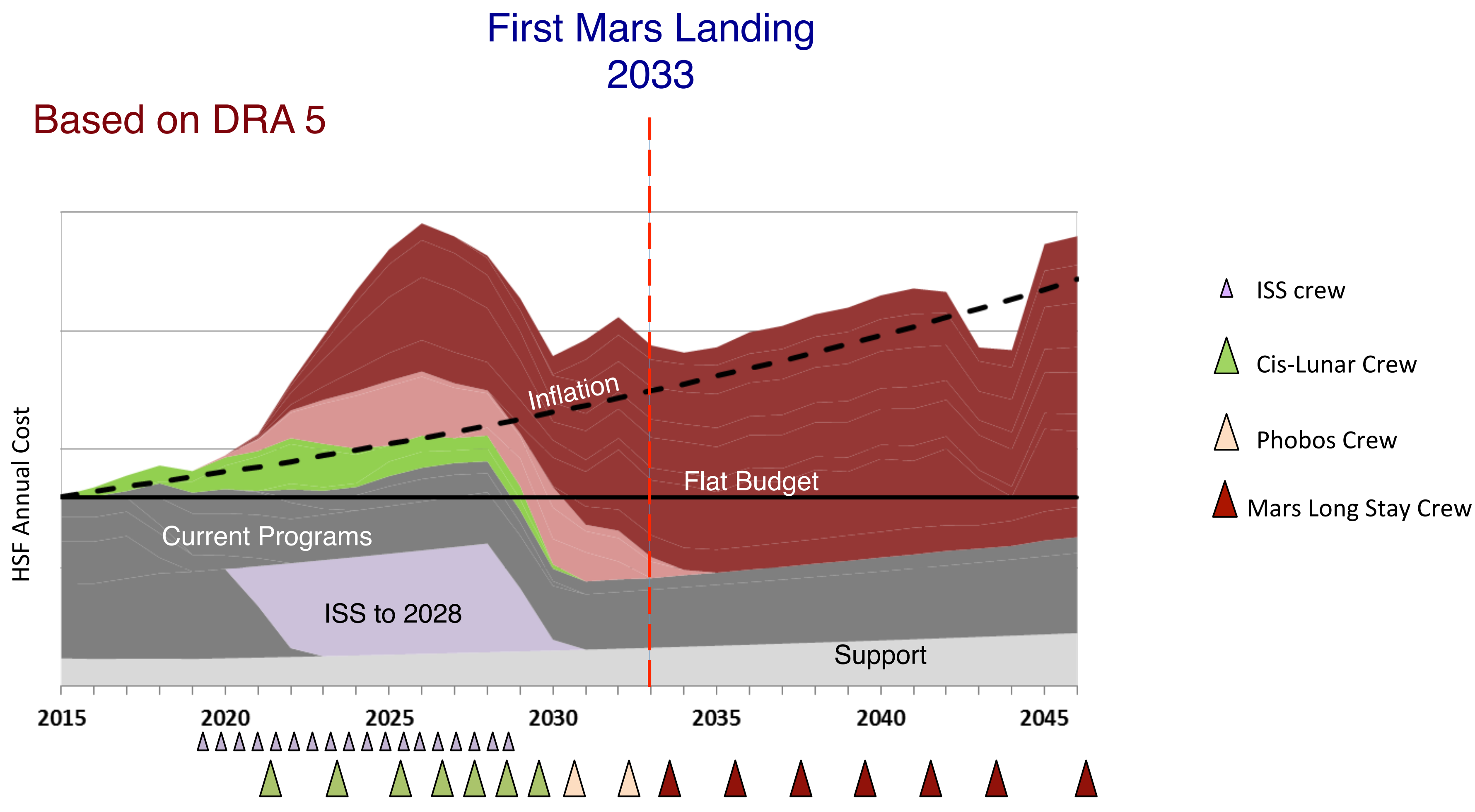
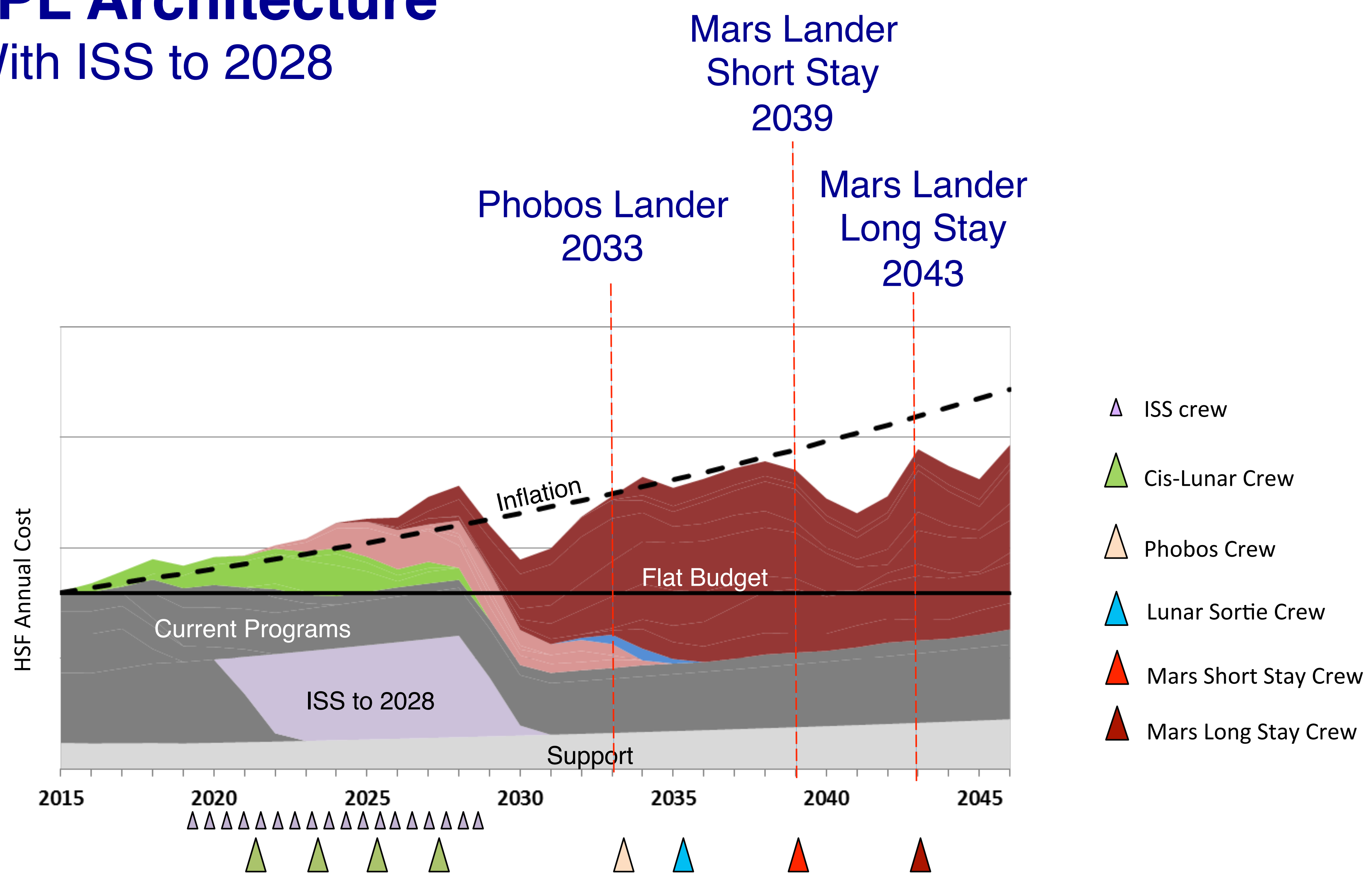
NRC Schedule Driven Pathway:
First Mars Landing by 2033



JPL Architecture
With ISS to 2028



Higher TRL elements present both less cost and less schedule risk

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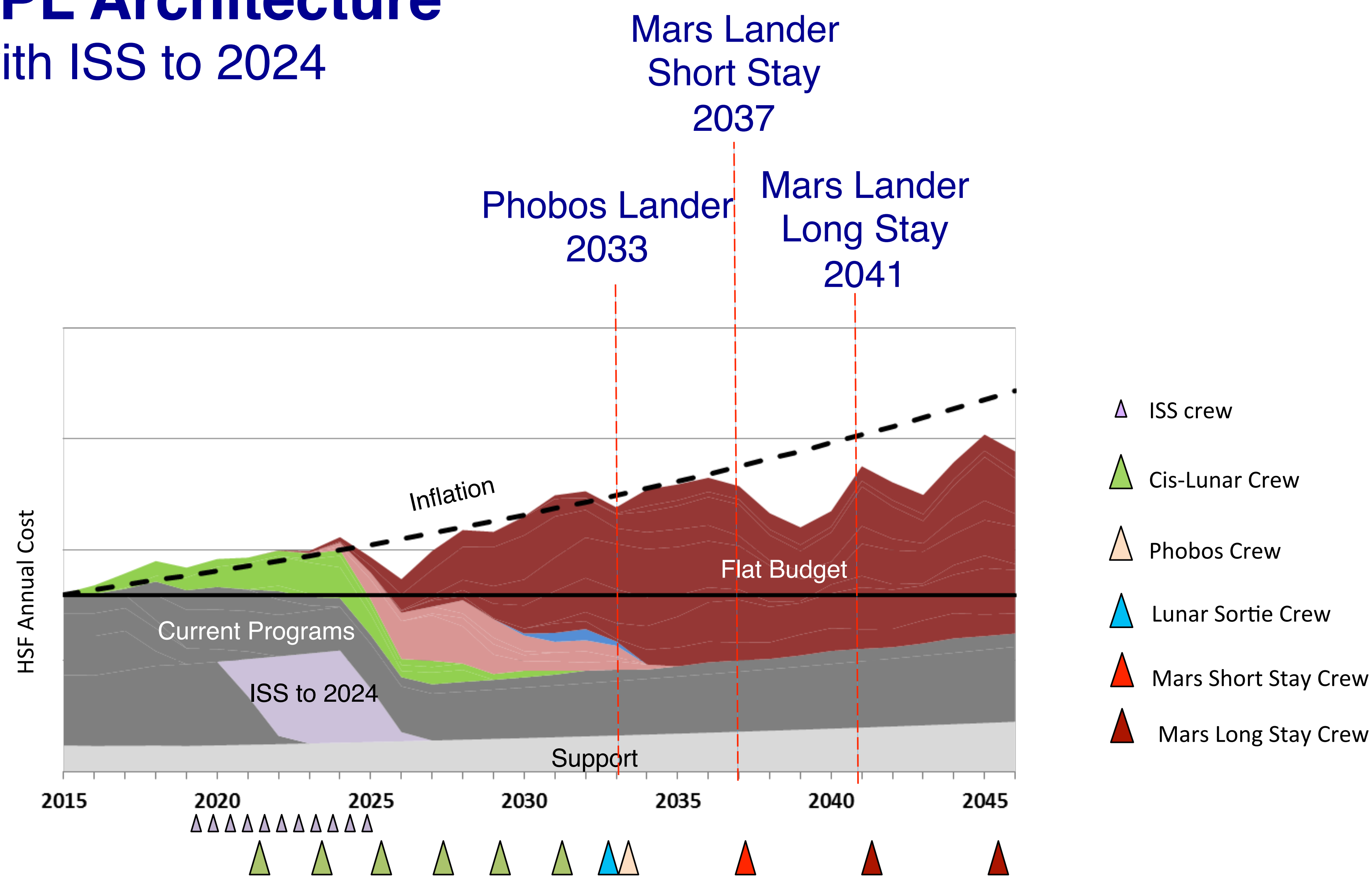
JPL Architecture
with ISS to 2024



This work was aimed at showing an example (an existence proof) that journeys to Mars using technologies that NASA is currently pursuing is plausible on a time horizon of interest to stakeholders and without large spikes in NASA budget.